

THE EFFECT OF RESPONSE-CONTINGENT FOOD-PAIRED
STIMULI IN RESPONSE ACQUISITION WITH DELAYED
PRIMARY REINFORCEMENT

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ABSTRACT

THE EFFECT OF RESPONSE-CONTINGENT FOOD-PAIRED STIMULI IN RESPONSE ACQUISITION WITH DELAYED PRIMARY REINFORCEMENT

by Andrew T. Fox

Several previous experiments have shown that brief stimuli presented at the beginning of response-reinforcer delays can attenuate the typical response-reducing effect of the delay with effectiveness equal to that of stimuli that fully span the delay. The mechanism underlying this effect is unclear. Four experiments were conducted that explored variables assumed to modulate the beginning-signal effect in response acquisition with delayed reinforcement. In Experiment 1, prior experience with the brief stimulus (forward versus backward light-food pre-pairing) and the immediacy of the brief stimulus during response acquisition (0, 3, and 12.5 s delayed) were manipulated across groups. In Experiment 2, delay and trace light-food pre-pairing were compared across groups receiving either a beginning signal or no signal during response acquisition. In Experiment 3, the type of stimulus (diffuse versus localized) was varied across groups. Experiment 4 was a systematic replication of Experiment 1 using a single 4-hr lever press acquisition session rather than 20 30-min sessions. Also included were a 6-s delayed brief stimulus group and an additional control group that did not receive pre-pairing experience but did get the brief signal during response acquisition. Results include the findings that backward pre-pairing suppresses the beginning-signal effect but trace pre-pairing does not; short delays to the brief stimulus do not impair the beginning-signal effect; and type of signal (diffuse or localized) does not matter. A modified view of conditioned reinforcement is proposed to account for the findings in these and other experiments on the beginning-signal effect in delayed reinforcement.

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CHAPTER I

INTRODUCTION

In operant conditioning, the delay between response and reinforcer has generally been considered to be one of the primary determinants of the strength of a reinforcer. Interest in delay-of-reinforcement in operant conditioning can be considered part of the broader topic of how the arrangement of events in space and time combine to determine behavior. Thorough understanding of the effects of delay-of-reinforcement in all of its myriad manifestations is therefore germane to the overarching goals of a science of behavior: prediction and control.

Delay of reinforcement in operant conditioning has been studied using an array of techniques. For instance, response-reinforcer delays can be instituted following establishment of a stable baseline in which no delay is present (the “steady-state” method). Alternatively, response-reinforcer delays can be present during acquisition of a novel response (the “acquisition” method). While neither method is inherently superior to the other from a theoretical standpoint, the steady-state method has historically received more attention than the acquisition method. A further distinction can be made between procedures using unsignaled versus signaled delays, although the paramount influence of this variable was only explicitly recognized relatively recently (Richards, 1981). An unsignaled delay is one that is not accompanied by some exteroceptive stimulus that is present during part or all of a response-reinforcer delay period; a signaled delay is one that does contain such an exteroceptive stimulus. Steady-state and acquisition studies have converged on the finding that unsignaled delays have much stronger detrimental effects on operant responding under most (but not all) circumstances.

One determinant of the effect of a delay signal is its temporal location within the delay. The most typical scenario involves signaling the delay in its entirety, but this need not be the case. Signals in either the middle or end of a delay, despite propinquity with primary reinforcement, have been shown to reduce responding below levels seen with unsignaled delays (e.g., Williams, 1999); however, the reliability of some of these findings is at least somewhat questionable (Fox & Reilly, 2010). Further, briefly signaling the beginning of a response-reinforcer delay can be equally as effective as completely signaling the delay (Schaal & Branch, 1988), an intriguing finding that has received little attention. The following set of experiments aims to explore this phenomenon using the response acquisition with delayed reinforcement paradigm.

CHAPTER II

LITERATURE REVIEW

In the interests of brevity and clarity the following review of the delayed reinforcement literature will largely exclude experiments conducted using less common instrumental tasks (e.g., t-maze and other discrete-trials procedures) as well as choice procedures (which comprises a vast but separable sub-field of behavioral studies). Additionally, studies using very short delays (0.5 s) will also be excluded because findings obtained using these delays are often opposite the effects obtained using larger delays (> 3 s; e.g., Arbuckle & Lattal, 1988) and do not bear heavily on the present set of experiments (which all will employ nominal delays of at least 5 s). Instead, this review will provide an overview of important findings and key experiments related to the following areas: (1) delayed reinforcement effects in steady-state and acquisition studies; (2) the effects of signaled delays; (3) the effects of signal location in partially-signaled delays; and (4) the effects of other experience with such signals.

Delayed Reinforcement Effects in Steady-state and Acquisition Studies

Operant conditioning research on delayed reinforcement using steady-state procedures can be characterized by three findings: 1) behavior can be maintained by delayed reinforcement; 2) the longer the delay between response and reinforcer the less effect the reinforcer has; and 3) firm evidence of the mechanism underlying delayed reinforcement's behavioral effects has been elusive. An early experiment by Ferster (1953) using pigeons established that introducing a 60-s blackout period in between response and reinforcer on behavior maintained by a variable-interval (VI) 60-s schedule of reinforcement substantially reduced, but did not eliminate, key-pecking in 3 of 4 subjects. Azzi, Fix, Keller, & Rocha e Silva (1964) extended Ferster's results to rats bar-

pressing under a fixed-ratio (FR) 1 schedule of reinforcement with a resetting delay contingency. Under such a schedule, a single response starts a timer which must elapse for the reinforcer to be delivered; further responses occurring during the delay interval serve only to reset the timer. Delay values ranging from 1 to 20 s were employed with the finding that response rate was approximately a decreasing hyperbolic function of delay in all three subjects. In other words, the decrease in response rate was much greater between 1 and 5 s than it was between 10 and 20 s. Morgan (1972) replicated the findings of Azzi et al. (1964) using a schedule other than continuous reinforcement (FR 9) and non-resetting delays. Morgan reported that the effect of delayed reinforcement on ratio schedules was mostly to increase post-reinforcement pausing and not to decrease rate of responding *per se*. Reilly and Lattal (2004; Experiment 1) noted that few studies had compared delayed reinforcement to an immediate reinforcement baseline in the absence of reductions in reinforcement rate associated with the delay conditions. Therefore, they devised an experiment in which each subject experienced two experimental sessions per day. In the first, reinforcers were delivered after increasingly long delays (a “progressive delay” procedure); in the second, reinforcers were “set up” to be delivered *immediately* at the same times as the subject earned them in the earlier session. Thus, each subject was “yoked” to itself; this procedure not only guaranteed that reinforcement *rate* was identical between delay and no-delay conditions but also that each individual reinforcer was delivered at approximately the same time. Their findings were threefold: 1) response rates were lower in all subjects under delayed reinforcement conditions regardless of whether the baseline schedule was fixed-interval (FI) or VI; 2) post-reinforcement pauses were longer under delayed reinforcement conditions; and 3) the relationship between response rate and nominal delay length was well-described by a negatively

decelerated hyperbolic function. Response-reinforcer delay, therefore, was unequivocally shown to have a large negative impact on responding under FI and VI schedules.

Other experiments used delay-of-reinforcement to explore the mechanisms underlying reinforcement itself. The debate often hinged upon whether contingency (the if-then relationship between behavior and consequence) or contiguity (the mere closeness in time between behavior and consequence) was the main determinant of a reinforcer's effectiveness. Williams (1976) imposed non-resetting delays of 3, 8, and 15 s on pigeons' key-pecking maintained by a VI 120-s schedule of reinforcement. Importantly, he included a yoked-control condition in which pigeons received reinforcers response-independently (i.e., in the absence of contingency) at the same time that other pigeons were receiving earned reinforcers. In most cases, responding dropped off at all delays and when the yoked-control condition was in effect, implying the importance of the response-reinforcer contingency in maintaining behavior in the absence of response-reinforcer contiguity. Gleeson and Lattal (1987) replicated Williams (1976) but, instead, employed a within-subjects yoking procedure. They found that the primary determinant of response rate was not response-reinforcer contingency but instead obtained delay (the actual time between responses and reinforcers), implying the importance of response-reinforcer contiguity. Weil (1984) used a unique, temporally-defined schedule of reinforcement to study the effects of delayed reinforcement in the absence of a relationship between increases in delay and decreases in reinforcement rate, a confound that previous studies had failed to avoid. Using regression analysis to predict response rates with obtained delay and obtained reinforcer frequencies as variables, Weil concluded that obtained delays (i.e., response-reinforcer contiguity) contribute to the response rate-reducing effects of delayed reinforcement more than any other variable.

Overall, the evidence indicates that both response-reinforcer contingency and contiguity can be shown to be important in the maintenance of behavior.

In addition to the findings from steady-state procedures, research on response acquisition with delayed reinforcement (RADR) can be characterized by three findings: 1) novel behaviors can be learned despite response-reinforcer delays of up to and including 32 s; 2) a wide variety of control procedures has proven that RADR is a genuine operant learning phenomenon; and 3) RADR is robust across a variety of species, strains, and reinforcer types. Experiments on response acquisition with delayed reinforcement often do not include comparisons between immediate and delayed reinforcement conditions like steady-state experiments do; instead, the question is under what conditions is RADR either possible or more likely. In an early experiment on RADR, Perin (1943) required rats to learn to press a bar in the opposite direction (left or right) than they had already been trained to press. Acquisition of this “response differentiation” was tested at delay values ranging from 0 to 30 s. Response latency was lowest and accuracy highest under the 0-delay condition but learning was still evident using delays of up to 10 s. Seminal research by Lattal and Gleeson (1990) firmly established the genuineness of the RADR phenomenon in the absence of immediate response-produced stimuli of any kind. Across six experiments, it was shown that RADR reliably occurred in pigeons and rats, with resetting and non-resetting unsignaled 30-s delays, with FR 1 and VI schedules, and with various operandum types and locations (both near and far from the food hopper). Importantly, at no time were their subjects hand-shaped or trained to respond. Additionally, extinction and response-independent food control conditions were conducted, thereby precluding interpretation of the results in terms of either incidental contact with the operanda or induction of responding by the presence of food

itself. While Lattal and Gleeson emphasized the lack of immediate response-produced feedback as separating their experiments from those that had come before, they also pointed out that the audible click made by the microswitch of a depressed key or lever is, in a sense, immediate response-produced feedback. A follow-up study (Critchfield & Lattal, 1993) showed RADR in the absence of response-produced feedback of this kind using a photobeam-break response as the to-be-learned target behavior. Further, studies from other labs confirmed the results of Lattal and Gleeson using similar procedures (e.g., Dickinson, Watt, & Griffiths, 1992; Wilkenfield, Nickel, Blakely, & Poling, 1992). Sutphin, Byrne, and Poling (1998) introduced a novel control procedure to the study of RADR. They compared RADR between rats given an alternative lever with either no function or a reinforcer-cancellation function. The alternative lever allowed each subject to serve as its own control; more pressing on the lever associated with reinforcement implies that the reinforcement contingency is controlling behavior. They found that responding tended to increase equally on both reinforcement and non-reinforcement levers at several delay values, but only in the condition where the alternative lever did not cancel the upcoming reinforcer. Bruner, Pulido, and Escobar (1999) used Weil's (1984) method (the "temporally-defined" schedule) to control overall reinforcement rates while examining different unsigned nominal response-reinforcer delays during acquisition. Their findings accorded with both Lattal and Gleeson's and Weil's: acquisition occurred even with large obtained delays but response rates were inversely related to delay length.

Response acquisition with delayed reinforcement has been studied across a variety of species, strains, and reinforcer types. Lattal and Gleeson (1990) used both pigeons and rats in their oft-cited experiments. Lattal and Metzger (1994) demonstrated that RADR was possible in

male Siamese fighting fish (*Betta splendens*) with a 10-s response-reinforcer delay. Monkeys (*Macaca mulatta*; Galuska & Woods, 2005) and humans (Okouchi, 2009) have also acquired novel behaviors despite 15- and 30-s delayed reinforcement in RADR experiments. The phenomenon is also robust across several rat strains including Sprague-Dawley (e.g., Williams, 1999), Lewis (Anderson & Elcoro, 2007), Wistar (Azzi et al., 1964), Wistar-Kyoto (Hand, Fox, & Reilly, 2006), and two strains known for increased sensitivity to response-reinforcer delays, the Spontaneously Hypertensive Rat (Hand et al., 2006) and the Fischer 344 (Anderson & Elcoro, 2007). An array of reinforcers has also been used successfully in RADR studies. These include food (e.g., Lattal & Gleeson, 1990), water (e.g., Snyckerski, Laraway, Huitema, & Poling, 2004), intravenous cocaine (Galuska & Woods, 2005), mirror access (Lattal & Metzger, 1994), and reinforcer-paired stimuli (Snyckerski, Laraway, & Poling, 2005).

Despite the generality of response acquisition with delayed reinforcement, several factors not related to delay length that limit response acquisition have been identified. Lattal and Williams (1997) identified the “establishing operation” of food restriction as a limiting factor in RADR using rats as subjects. (An establishing operation is any manipulation that increases the effectiveness of a reinforcer; in the case of food reinforcers, reducing body weight is a common tool for ensuring reinforcer effectiveness.) They found a clear relationship between severity of food restriction and the likelihood of lever-press acquisition using a 30-s resetting delay; 5 of 5 rats deprived to 70% of their previous body weights acquired lever-pressing within a few sessions whereas 0 of 5 rats deprived to 90% acquired lever-pressing quickly. Black, Beluzzi, and Stein (1985) attempted to use electrical brain stimulation as the reinforcer for rats learning to lever-press with an unsignaled resetting delay of 1, 2, 3, or 6 s. Response acquisition was

severely impaired compared to an immediate-reinforcer control group at even the shortest delay tested (1 s). Rats in the 6-s delay condition did not learn to lever press at all. Snyckerski et al. (2004) showed that previous experiences in the operant chamber can hinder response acquisition. In their experiment, both brief magazine training (1 session versus 5) and the presence of the lever during magazine training hindered acquisition of lever pressing with delayed reinforcers. Finally, certain rat strains seem to be genetically predisposed to poorer learning when delay of reinforcement is involved. For instance, both the Fischer 344 (Anderson & Elcoro, 2007) and Spontaneously Hypertensive Rat (Hand et al., 2006) strains have been shown to exhibit impaired learning under the RADR paradigm.

The Effects of Signaled Delays

Whereas the literature on delay of reinforcement *per se* is expansive, research designed to explicitly compare signaled to unsignaled delays is relatively scarce. However, as long as the response-reinforcer delay is longer than 0.5 s, the effects of signaled delays are quite consistent: signaling a response-reinforcer delay negates the response-reducing effect of the delay itself. In other words, while even a short unsignaled delay can have large detrimental effects on response rate, a long signaled delay will often have little effect.

Research comparing signaled to unsignaled delays has mostly been accomplished using steady-state procedures. An early study by Azzi et al. (1964) compared FR 1 responding with a 20- or 30-s resetting delay both with and without delay-associated illumination changes. Response rates were higher and responding more regular with signaled delays. Richards and Hittesdorf (1978), in an experiment primarily on stimulus generalization, imposed 10-s unsignaled and signaled delays upon pigeons responding on VI 60-s schedules of food

reinforcement. Regardless of the type of signal employed (four were tested), key-pecking rates were always higher (on average, 2 to 3 times higher) when the delay was signaled compared to when it was unsignaled. Richards (1981) followed up this experiment with another designed to replicate this basic finding with both decreases and increases in the rate of primary reinforcement and across a range of delays (.5 to 10 s). This was accomplished by dividing the subjects into two groups, one with a VI 60-s baseline schedule and the other with a differential-reinforcement-of-low-rate (DRL) 20-s schedule and applying the different delay values across conditions for all subjects. Under a DRL schedule, a response must at least t s (20, in this case) removed from the previous response to be eligible for reinforcement. The DRL schedule was chosen because when response rate decreases on this schedule, a subject is more likely to emit an inter-response time that is long enough to meet the criterion for reinforcement; hence, delays should (and did) *increase* reinforcement rate on this schedule. The effects of signaled and unsignaled delays were consistent across subjects and both the VI and DRL baselines: large declines in response rate were evident at longer unsignaled delays but the similar declines were not evident with signaled delays of the same length. An experiment by Williams and Heyneman (1982) showed that a signaled delay of 3 s imposed upon a VI 3-min baseline schedule of food reinforcement in pigeons had little effect on behavior whereas an unsignaled 3 s delay halved response rates. Schaal and Branch (1988; Experiment 2) achieved an even larger disparity between response rates maintained by signaled and unsignaled 3-s delays with a VI 60-s baseline schedule (rates were around 3 to 6 times higher under the signaled condition, depending on the subject). Reilly and Lattal (2004; Experiment 2) compared unsignaled and signaled delays using their within-session progressive delay procedure described above (minus the self-yoking procedure). They

found consistent and large enhancing effects on the amount of behavior maintained when the delays were signaled with blackout; response rates were higher and subjects responded at least some at massively longer delays (up to 6 min compared to 1 or 2 min in most cases).

One further experiment using a steady-state procedure is of note because of the unique control procedures that were employed. Lattal (1984) noted that: 1) response-reinforcer delays had often been signaled with blackout periods associated with nonreinforcement and 2) that such periods alternating with periods of reinforcement often serve to increase response rates in behavioral contrast experiments. Therefore, the effect of these blackouts as delay signals could not be separated from their effect as periods of nonreinforcement in previous studies. The solution was to compare unsignaled to signaled delays with the addition of several control conditions that varied the degree to which the blackout period actually occurred between response and reinforcer. This was accomplished both by randomly presenting blackout periods throughout the session and by presenting blackout periods (that did not end in reinforcer delivery) contingent upon keypecks. The finding was that only when the blackout period was between response and reinforcer was there an effect of the signal. In other words, blackout periods *per se* were not crucial to the effect; their relationship to responses and reinforcers was.

Two studies can be identified as having examined response acquisition with both unsignaled and fully-signaled delayed reinforcement. Tombaugh and Tombaugh (1971) used a discrete-trials procedure in which a lever was inserted into the operant chamber and rats had 60 s in which to press it. If a lever press occurred, the lever retracted and a sugar water reinforcer was delivered 7.5 s later. For some subjects, the houselight turned off and another light in the water delivery magazine was illuminated for the extent of the delay. (While the subjects in the

unsignaled condition did not technically experience an “unsignaled” delay to the extent that lever retraction can be considered a signal, a comparison with the group receiving the illumination change correlated with the delay is still useful for the present purpose.) Learning was measured by plotting latency between the start of a trial (i.e., insertion of the lever) and a lever press across blocks of 30 trials. The result was that the group with the signaled delay exhibited lower latencies across all 8 blocks of trials than the group with the “unsignaled” delay. In a free operant study using response rate as the dependent variable, Rull, Gonzalez, and Hoekstra (2008) compared response acquisition across subjects given either unsignaled or completely signaled 32-s delays using temporally-defined schedules of reinforcement. Again, the finding was that acquisition was stronger and response rates higher in the group with the signal. The effect of signaling response-reinforcer delays appears to be consistent across both response acquisition and steady-state procedures: delayed reinforcers have much weaker detrimental effects on responding when they are signaled.

Signal Location Effects

In addition to studies that have compared unsignaled to completely signaled delays, many experiments have also employed partially-signaled delays. Partially-signaled delays can be placed into three broad categories: those in which the signal is contiguous with the response but not the reinforcer, those in which the signal is contiguous with the reinforcer but not the response, and those which the signal is contiguous with neither the response nor the reinforcer. These categories can alternatively be labeled as having signals at the beginning, end, or middle of response-reinforcer delays, respectively. Studies employing partially-signaled delays in steady-state and response acquisition procedures will be considered in turn.

Steady-state procedures using partially-signaled delays have revealed that the effect of a non-completely signaled delay depends critically upon the placement of the signal within the delay. Generally speaking, signals that are not contiguous with the response reduce responding below levels seen with unsignaled delays. On the other hand, signals that are contiguous with the response often have similar effects to signals that span the entire delay. Demonstrations of the former come from Williams (1975, 1978) and Williams, Preston, and de Kervor (1990; Experiments 1 & 2). Williams (1975) trained pigeons on a discrete-trials procedure in which at least one key-peck during a 5-s red keylight presentation resulted in access to grain 9 s after keylight offset. Pigeons presented with a green key (which they had been pretrained to peck) during the last 4-s of the 9-s delay earned fewer reinforcers than pigeons not presented with the green key. In a follow-up experiment using a similar procedure, Williams (1978) determined that the type of signal was not crucial; a tone that did not elicit key-pecking functioned the same as a keylight that did. In an unusual finding, the placement of the signal within the delay (beginning versus end) did not matter; both placements suppressed responding. It should be noted that, like the Tombaugh and Tombaugh (1971) experiment reported above, the comparison in Williams' (1975, 1978) experiments was not properly between "unsignaled" and "partially-signaled" delays. Rather, the comparison was between delays signaled by blackout and delays signaled by blackout *and* another partial signal. This issue was cleared up by Williams, Preston, and de Kervor (1990), who not only compared unsignaled delays to partially signaled delays, but also did so using a within-subjects, free operant design. Each of eight pigeons was exposed to a four-component multiple schedule in which the condition changed every 340 s and each component was signaled by its own color of keylight. The base schedule of reinforcement in each

component was VI 60-s. In one component, an unsignaled 8-s delay terminating in food delivery followed completion of the VI 60-s schedule requirement. In two other components, a colored houselight turned on either during the first or last 2 s of the otherwise unsignaled 8-s delay. In a no-delay control component, a fixed-interval 8-s schedule followed completion of the VI 60-s. On average, the component with the signal at the end of the delay produced the lowest response rates, which were about 50 percent below both the roughly equal beginning-signal and no signal components. Upon changing the stimuli associated with the beginning-signal and no signal components, an enhancing effect of the beginning signal also emerged. A second experiment showed that a 2-s signal in the middle of the delay had the same effect as a signal at the end of the delay, a reduction in response rate below that seen with a completely unsignaled delay.

Other research has focused primarily upon effects of partially-signaled delays in which the signal is contiguous with the response. One study from Lieberman, Davidson, and Thomas (1985) showed that a 1-s stimulus change at the start of a 6-s delay enhanced a left/right discrimination in pigeons. Studies using free operant procedures with response rate as the dependent measure come from Branch and colleagues (Schaal & Branch, 1988, 1990; Schaal, Schuh, & Branch, 1992). In Schaal and Branch (1988), pigeons were exposed to VI 60'' schedules of food reinforcement with response-reinforcer delays of various lengths (up to 27 s). Under a 1-s unsignaled delay, response rates dropped noticeably. However, under 1-, 3-, and 9-s (but not 27-s) delays with a 0.5-s keylight color change at the beginning of the delay, response rates were generally indistinguishable from a no-delay baseline. A follow-up experiment (Schaal & Branch, 1990) demonstrated a strong direct relationship between the length of the response-produced signal and response rate using a VI 60'' schedule with a 27-s delay. In other words, the

longer the signal, the more behavior it maintained. Schaal, Schuh, and Branch (1992) placed pigeons on a multiple VI 20'' VI 120'' schedule of reinforcement with 5-, 10-, and 20-s briefly signaled delays. The signal had no effect on behavior under 20-s delays on the VI 20'' schedule but did have the typical delay-immunizing effect on behavior maintained by the VI 120'' schedule. In other words, whether the brief response-produced signal increased response rate was dependent upon the ratio of the delay length to the average inter-food interval and not just delay length itself.

Research using acquisition procedures has generally been consistent with research using steady-state procedures. The Tombaugh and Tombaugh (1971) study mentioned above also included groups receiving beginning- and end-of-delay signals that learned with speed intermediate to the groups with no signal and a complete signal. The lack of effect of location of the signal is consistent with Williams (1978) although the signal effect is in the opposite direction. It should be noted that these two studies are the least consistent with the remaining literature and that neither of these studies contained truly unsignaled delays as control conditions. Williams et al. (1990; Experiment 3) and Williams (1999) both examined RADR in rats with end-of-delay signals. In Williams et al., rats were magazine trained for one session using food pellet deliveries (every 90 s, on average) that were preceded by a 5-s houselight presentation. In the second session, a lever was introduced into the operant chamber and a 30-s non-resetting delay-of-reinforcement period was initiated upon a single lever press; meanwhile, the free food deliveries continued. For one group, a 5-s houselight presentation occurred at the end of the delay; for the control group, no such signal was presented. Although no data were given on response rates, the group that got the signal at the end of the delay took longer to reach 100

cumulative responses. It should also be noted that one attempt to replicate this experiment in our lab revealed no effect of the signal, although none of our subjects actually acquired lever pressing. Williams (1999) replicated Williams et al. (1990; Experiment 3) with the inclusion of a group with a signal at the beginning of the delay and cessation of the free food deliveries after magazine training. Again, lever press acquisition was retarded in the group with the signal at the end of the delay. Additionally, acquisition was enhanced in the group with the signal at the beginning of the delay. It should again be noted that replications of this experiment in our lab have shown no effect of the end-of-delay signal (Fox & Reilly, 2010).

Others, however, have confirmed the robustness of the beginning-signal effect. Critchfield and Lattal (1993) examined acquisition of a “spatially-defined” response (a photobeam-break instead of a lever press) in rats using a resetting 30-s response-reinforcer delay. For some rats, a tone sounded briefly upon breaking the photobeam; for others, no such tone sounded. Acquisition was slightly enhanced by the presence of the response-produced tone. Schlinger and Blakely (1994) replicated this finding (including the use of the “spatially-defined” response) using shorter delays of 4 and 10 s and their effect was substantially stronger than that seen in Critchfield and Lattal (1993). More recent research on beginning-signal effects has been conducted using temporally-defined schedules. Pulido, Lopez, and Lanzagorta (2005) arranged it so that a lever press occurring within the first t s (dubbed period “ t^d ”) of a 32-s period resulted in food at the end of the 32 s. For some subjects, a tone and illumination change that lasted until the end of t^d accompanied an effective lever press; for other subjects the delay was always completely unsignaled. Acquisition was stronger in the subjects that received the response-produced signal, particularly when t^d was 4 s as compared to 8 s. Rull, Gonzalez, and Hoekstra

(2008) conducted a very similar study in which the length of the signal was varied across subjects. They found a direct positive relationship between the length of the signal and the strength of response acquisition for both the 4- and 8-s t^d conditions. This finding meshes perfectly with the steady-state experiment of Schaal and Branch (1990) who found the same relationship between delay length and response rate in pigeons. All told, the research using partially-signaled delays is remarkably consistent across steady-state and acquisition procedures.

Other Experience with Signals

The extent to which the function of a delay signal is dependent upon subjects' prior experience with the signal has not typically been a primary research question. For instance, the group from Williams (1975) that experienced a 4-s green keylight presentation at the end of a delay had prior experience in which that signal was paired with food. However, this group was not compared to a control group that did not have this prior experience; therefore, the extent to which the previous experience with the green light contributed to the effect of the signal is unknown. A second experiment did show that concurrent extinction of responding to the green key eliminated the suppressive effect of the delay stimulus presentation. None of the experiments in Williams (1978) contain comparisons between stimuli previously paired with food and unpaired ones, despite the presence of a stimulus that was explicitly unpaired with food that could have been used as a delay stimulus. Likewise, a study by Williams, Preston, and de Kervor (1990; Experiment 3) involved pairing of the houselight with food delivery prior to and during the response acquisition part of the experiment. Again, because no unpaired control condition was conducted, it is unclear whether the pairing itself exerts any effect upon the function of the signal when it is presented during the delay. Dickinson, Watt, and Varga (1996) showed that

signaling free food deliveries during magazine training had an enhancing effect on later response acquisition with delayed reinforcement. However, in their study, no signals were presented during response-reinforcer delays; any effect of the pre-exposure to the signal could not be attributed to its current function. Schaal, Shahan, Kovera, and Reilly (1998) showed that a response-contingent signal's function changed drastically depending on whether it was paired with food or explicitly unpaired with food; pigeons continued to key peck despite the lack of response-food contingency as long as the response-produced signal was paired with food. However, while this suggests that the function of immediate response-produced signals occurring during delays to primary reinforcement is dependent upon a history of signal-food pairing, it does not provide direct evidence because the signals were never presented during delays to primary reinforcement in this experiment. Snyckerski, Laraway, and Poling (2005) gave water-deprived rats experience with response-independent water dipper presentations followed by acquisition sessions in which an empty dipper was presented response-contingently at delays of 0, 15, 30, and 45 s. Most of their rats acquired lever-pressing regardless of delay as compared to controls that had not experienced the sessions of response-independent water dipper presentations. In this case, prior experience with a stimulus imbued it with apparent reinforcing efficacy, although how such a stimulus would have functioned had it been presented during a delay to primary reinforcement remains unknown. Perhaps the most compelling evidence of the effect of prior experience on the function of an immediate response-contingent delay stimulus comes from the Schaal and Branch (1990) experiment mentioned above. In their experiment, two orders of conditions were arranged in separate components of a multiple schedule. In one component, the length of the beginning-delay signal increased from 0.5 to 27 s across conditions;

in the other, it decreased from 27 to 0.5 s. The shortest signal durations functioned to maintain higher levels of responding in all three subjects in the component with the descending order of signal durations. This implies that the prior experience of the signal closely preceding the primary reinforcer was a fundamental determinant of the signal's function.

Current Aims

The broad aim of the present set of investigations is to expand the literature pertaining to immediate response-produced stimuli and their effect on operant behavior maintained by delayed primary reinforcement. In choosing between steady-state and response acquisition methods, the response acquisition method would seem to be the best suited to study of the effects of prior experience with stimuli used to signal the beginning of response-reinforcer delay because, using the steady-state method, a signal would be more likely to change in function (or lose function) over the course many sessions. Further, this potential area of research has remained virtually untouched at the time of this writing.

The present set of experiments aims to contribute to the understanding of the mechanism underlying beginning-signal effects. Explanations of the effect generally fall into two categories: “marking” and conditioned reinforcement. The marking explanation posits that signals that occur immediately after responses serve to “mark” the preceding event in memory, thus making it more retrievable upon reinforcer delivery. Critics have argued that this is a non-explanation that amounts to little more than circular reasoning (e.g., Schlinger & Blakely, 1994). More traditional accounts have appealed to conditioned reinforcement as the explanation for the facilitative effects of beginning signals (e.g., Schaal & Branch, 1988). Such an account typically rests on the assumption that for the signal to have a facilitative effect it must have been paired with the

primary reinforcer (or another already-established conditioned reinforcer) in some way, so that Pavlovian conditioning between the stimulus and the reinforcer could occur. Critics of this explanation have pointed out that in some cases of facilitative effects of beginning signals, there is too large a temporal gap between the signal and the primary reinforcer to consider Pavlovian conditioning to have occurred (Williams, 1999). A third possibility exists: sensory reinforcement. A sensory reinforcement explanation would posit that immediate response-produced stimuli are essentially primary reinforcers; such effects have been observed in an array of studies (e.g., Barry & Symmes, 1963). Because response acquisition studies have not compared groups receiving pre-exposure to the delay stimuli to those that have not had such experience, the sensory reinforcement and conditioned reinforcement accounts have not been disentangled. One solution (which will be employed in Experiment 1) is to pair the delay stimulus with food prior to acquisition sessions for some subjects. If pairing with the primary reinforcer is crucial to the facilitative effect of beginning signals, these subjects should show a larger facilitative effect than subjects given no such experience. If sensory reinforcement is an underlying mechanism, both groups of subjects should show a facilitative effect compared to controls given no delay signal. An additional purpose of Experiment 1 is to conduct a parametric assessment of the effect of delay to the response-produced signal. A delay gradient produced as a function of increasing delay to the signal would imply that the signal functions like a reinforcer.

Experiments 2 through 4 assess other variables within this paradigm. In Experiment 2, the nature of stimulus-food pre-pairing was varied (delay versus trace conditioning) to determine its effect on response acquisition with an immediate response-contingent stimulus presentation. Presumably, trace conditioning, in which there is a temporal gap between the offset of the

conditioned stimulus (hopper light) and the unconditioned stimulus (food delivery) will lead to weaker conditioning than delay conditioning, in which there is no such temporal gap. Therefore, the groups that experience trace pre-pairing should show weaker lever acquisition than the group that experiences delay pre-pairing. This outcome would be consistent with a traditional Pavlovian account of conditioned reinforcement. However, if the groups acquire lever pressing with equal speed relative to no-signal controls, the argument that beginning-signal effects are mediated by a mechanism other than Pavlovian pairing would be strengthened. Alternatively, experience with a temporal gap between the hopper light and food may facilitate response acquisition due the similarity between this pre-training arrangement and the arrangement during response acquisition, in which there will also be a temporal gap between hopper light offset and food delivery.

In Experiment 3, the nature of the signal itself [diffuse (housetlight) versus localized at food source (hopper light)] will be varied. The nature of a signal can sometimes be critically important (e.g., Reed, 2003; Tomie, 1995), so it would add to the generality of the beginning-signal effect if a direct comparison between signal types revealed no difference. Conversely, because diffuse signals (e.g., houselights & tones) have almost exclusively been used in prior studies, it would be informative (and a novel finding) if a localized stimulus exerted a stronger effect in this procedure than a diffuse one. Additionally, it is possible that the lack of strong signal effects in previous experiments in our lab (Fox & Reilly, 2010) might have been due to the ineffectiveness of the particular houselight stimulus that was used in those experiments. If the houselight is just as effective a signal as the localized hopper light, this possibility is weakened significantly.

Experiment 4 will be a systematic replication of Experiment 1 except that operant response acquisition will be observed in a single extended session (rather than many short sessions) following pretraining. It is presumed that pre-pairing will exert the strongest effect at the beginning of lever-press acquisition and that this manner of observing acquisition may lead to larger signal effects. Additionally, some subjects will experience the beginning-of-delay signal during operant response acquisition without having experienced signal-food pre-pairing. This arrangement is equivalent to the “marking” preparation described above and will allow a determination of the contribution of the pre-pairing over and above the effect of the beginning-of-delay signal itself.

It is worth noting that prior studies using partially-signaled delays often have not contained dependent measures that confirm the effectiveness of the delay signals independently of effects on target responding itself. In other words, no direct evidence is given that the signals, which are often putative Pavlovian conditioned stimuli, are eliciting conditioned responses. The present series of experiments will employ a method that explicitly measures responses to the putative conditioned stimulus. Namely, during light-food pairing, “head-in-hopper” behavior will be measured using a photobeam mounted in the food delivery trough. Lever-press acquisition will commence only when subjects are reliably approaching the food trough upon light onset, as measured by the photobeam-break response. To my knowledge, this will represent a novel contribution to the study of partially-signaled response-reinforcer delays.

In sum, the present series of experiments contributes to the literature on delayed reinforcement in two ways. First, it expands the growing literature on response acquisition with delayed reinforcement, which has become a fruitful area of research over the past twenty years.

Second, it contributes to the scarce but potentially important literature on partially-signalized delays by further exploring the mechanisms underlying and constraints upon the beginning-signal effect, which has received less attention than it deserves given the challenge to the traditional understanding of signalized delays that it poses.

CHAPTER III

METHOD

Experiment 1 – Immediate Versus Delayed Response-Contingent Food-Paired Stimuli

Subjects

Thirty-five male, experimentally naïve, CD[®]-IGS (standard albino laboratory rats) were used. Subjects were housed singly in hanging wire cages with free access to water and were maintained at 85% of their free-feeding weights by carefully measured daily feedings. All rats were housed in a colony room with a reverse 12:12 light/dark cycle operating (lights on at 2000 hrs) with sessions conducted during the dark part of the cycle. Sessions were conducted six to seven days per week at approximately the same time every day.

Apparatus

Four identical Coulbourn Instruments (Allentown, PA) experimental chambers measuring 29 cm high by 28.5 cm long by 25 cm deep were used. The work panel contained a rolled steel lever measuring 3.5 cm wide, protruding 2 cm from the wall and requiring a minimum force of approximately 0.25 N to operate. The center of the lever was located 4.5 cm from the left chamber wall and 14 cm from the floor. Horizontally centered on the front panel 2 cm from the floor was a 3 cm wide by 4 cm tall by 2 cm deep recess into which 45-mg Bio-Serv[®] Dustless Precision Pellets (Product #F0021) were delivered (this recess is known as the “magazine”). In the ceiling of this recess was a 14.4-V miniature light bulb (known as the “hopper light”). A photobeam was located within the recess in such a way that retrieval of food pellets was impossible without breaking the beam (the computer recorded whenever the beam was broken;

in this manner “head-in-hopper” behavior was tabulated). A 28-V houselight was located directly in the middle of the back panel 1.5 cm from the ceiling. All chambers were housed in large sound/light attenuating chambers. An IBM[®]-compatible computer running Microsoft Windows XP[®] and Graphic State v. 3.01 software provided control of stimuli and recording of data.

Procedure

All rats experienced two phases: magazine training and lever press acquisition. During magazine training sessions, the lever was not present in the operant chamber and food pellets were delivered response-independently on the average of every 90 s [a variable-time 90-s (VT 90-s) schedule of food delivery] until 30 pellets were delivered. For 28 of the rats (Forward Pairing group), a 5-s hopper light presentation immediately preceded all pellet deliveries during magazine training. Beam-breaks occurring in the 3 s before the hopper light was to be turned on delayed hopper light onset for 3 s. This reset contingency was done to ensure that rats will have to enter the pellet delivery recess after the hopper light presentation and to prevent adventitious reinforcement of head-in-hopper behavior by hopper light onset. For the other 7 rats (Backward Pairing group), the 5-s hopper light stimulus commenced 3 s after pellet delivery except that the 3-s reset contingency was also in place for these subjects (i.e., the hopper light turned on post food delivery as soon as 3 s elapsed without a beam-break). This condition was implemented to control for experience with both the hopper light and food pellets but without providing explicit forward pairing of the light and food. The pellet delivery trough was examined for remaining pellets immediately after each session to ensure that the rats consumed the pellets. Rats that did not consume all 30 pellets were given access to 5 pellets in a dish in the home cage. Once those pellets were consumed, 3 pellets were placed in the food magazine at the start of the next session

and the rat was monitored until the 3 food pellets were consumed, at which point the session was begun. The magazine training phase concluded for a Forward Pairing-group subject when it exhibited at least one photobeam break during 80% or more hopper light presentations [such a photobeam break was dubbed a conditioned response (CR)]. A matched Backward-Pairing subject received the same number of sessions as the 7 Forward-Pairing subjects that were assigned to the 0-s delay condition for lever press acquisition, thereby ensuring equivalent exposure to the magazine training phase across these groups. Beginning with the first session after the 80% criterion was met, the lever press acquisition phase began. During these sessions, a single lever press (not occurring during a response-reinforcer delay) initiated a 30-s non-resetting delay after which one food pellet was delivered. Lever presses occurring during delays were tabulated but had no programmed consequences. Each of 20 lever-press acquisition sessions lasted 30 min.

Four different stimulus conditions during response-reinforcer delays were arranged. For two groups, (7 of the Forward Pairing subjects and the 7 Backward Pairing subjects) the hopper light was illuminated during the first 5 s immediately after an effective lever press. For a third group (3-s delay), the 5-s hopper light stimulus commenced 3 s after an effective lever press. For a fourth group (12.5-s delay), the 5-s hopper light stimulus commenced 12.5 s after an effective lever press. For a fifth group (No Signal), no stimulus occurred during response-reinforcer delays.

Experiment 2 – Delay Versus Trace Conditioning During Stimulus-Food Pairing

Subjects

36 male, experimentally naïve, CD[®]-IGS rats were used. They were maintained identically to those in Experiment 1.

Apparatus

The same operant chambers and computer as Experiment 1 were used.

Procedure

Again, all rats experienced two phases: magazine training and lever press acquisition. During magazine training sessions, the lever was not present in the operant chamber and food pellets were delivered according to a VT 90-s schedule until 30 pellets had been delivered. For one-third (12) of the rats (0-s Trace group), a 5-s hopper light presentation immediately preceded all pellet deliveries during magazine training. For another third of the rats (2-s Trace group), the 5-s hopper light stimulus terminated 2 s before pellet delivery. The other third of the rats (5-s Trace group), the 5-s hopper light stimulus terminated 5 s before pellet delivery. The same 3-s reset contingency from Experiment 1 was employed for all three groups; the hopper light only turned on if there was no beam-break detected in the prior 3 s. The pellet delivery trough was examined for remaining pellets immediately after each session to ensure that the rats consumed the pellets. The same remediation procedure from Experiment 1 was employed for rats that did not eat all of the pellets. The magazine training phase concluded for a 5-s Trace group subject when it exhibited at least one photobeam break during 80% or more hopper light presentations or until 10 sessions had been conducted, whichever came first. Subjects in the other groups received

the same number of sessions as the 12 5-s Trace subjects, thereby ensuring equivalent exposure to the magazine training phase across the groups. Beginning with the first session after the 80% criterion had been met, the lever press acquisition phase began. During these sessions, a single lever press (not occurring during a response-reinforcer delay) initiated a 30-s non-resetting delay after which one food pellet was delivered. Lever presses occurring during delays were tabulated but had no programmed consequences. Again, twenty 30-min lever-press acquisition sessions were conducted.

Two different stimulus conditions during response-reinforcer delays were conducted. For one group, (composed of six 0-s Trace, six 2-s Trace, and six 5-s Trace subjects) the hopper light was illuminated during the first 5 s immediately after an effective lever press (Beg Sig). For the remaining subjects, no stimulus occurred during response-reinforcer delays (No Sig).

Experiment 3 – Diffuse Versus Localized Food-Paired Stimuli

Subjects

16 male, experimentally naïve, Sprague-Dawley rats were used. They were maintained identically to those in Experiment 1.

Apparatus

The same operant chambers and computer as Experiment 1 were used.

Procedure

All rats experienced two phases: magazine training and lever press acquisition. During magazine training sessions, the lever was not present in the operant chamber and food pellets were delivered according to a VT 90-s schedule of food delivery until 30 pellets had been

delivered. For half (8) of the rats (Houselight group), a 5-s *housetlight* (not the hopper light) presentation immediately preceded all pellet deliveries during magazine training. For the other half (Hopper Light group), a 5-s *hopper light* presentation immediately preceded all pellet deliveries during magazine training. The same 3-s reset contingency from Experiment 1 was employed for both groups; the hopper light or houselight only turned on if there was no beam-break detected in the prior 3 s. The pellet delivery trough was examined for remaining pellets immediately after each session to ensure that the rats consumed the pellets. The same remediation procedure from Experiment 1 was employed for rats that did not eat all of the pellets. The magazine training phase concluded for each subject when it exhibited at least one photobeam break during 80% or more hopper light presentations or until 10 sessions had been conducted, whichever came first. Beginning with the first session after the 80% criterion had been met, the lever press acquisition began. During these sessions, a single lever press (not occurring during a response-reinforcer delay) initiated a 30-s non-resetting delay after which one food pellet was delivered. Lever presses occurring during delays were tabulated but had no programmed consequences. Each of 20 sessions ended after 30 min.

Two different stimulus conditions during response-reinforcer delays were conducted. For the Houselight group, the houselight was illuminated during the first 5 s immediately after an effective lever press. For the Hopper Light group, the hopper light was illuminated during the first 5 s immediately after an effective lever press.

Experiment 4 – Marking Versus Conditioned Reinforcement

Subjects

30 male, experimentally naïve, Sprague-Dawley rats were used. They were maintained identically to those in Experiment 1.

Apparatus

The same operant chambers and computer as Experiment 1 were used.

Procedure

All rats experienced two phases: magazine training and lever press acquisition. During magazine training sessions, the lever was not present in the operant chamber and food pellets were delivered according to a VT 90-s schedule of food delivery until 30 pellets had been delivered. The rats were divided into 5 equal groups of 6 rats each. For two groups (Forward Pairing), a 5-s hopper light presentation immediately preceded all pellet deliveries during magazine training. Beam-breaks occurring in the 3 s before the hopper light was to be turned on delayed hopper light onset for 3 s. For one group (Backward Pairing), the 5-s hopper light stimulus commenced 3 s after pellet delivery except that the 3-s reset contingency was also in place for these subjects (as in Experiment 1). This control condition resulted in equal experience with both the hopper light and food pellets but inhibitory conditioning, if any, to the hopper light. For the other two groups (No Pairing), no stimuli were presented during magazine training. The pellet delivery trough was examined for remaining pellets immediately after each session to ensure that the rats consumed the pellets, which they invariably did. The magazine training phase concluded for a Forward Pairing group subject when it exhibited at least one photobeam break

during 80% or more hopper light presentations for one session. The Backward Pairing and No Pairing subjects received the same number of sessions as the Forward Pairing subjects, thereby ensuring equivalent exposure to the magazine training phase across these groups. After the 80% criterion had been met, one 4-hr lever press acquisition session was conducted. During this session, a single lever press (not occurring during a response-reinforcer delay) initiated a 30-s non-resetting delay after which one food pellet was delivered. Lever presses occurring during delays were tabulated but had no programmed consequences.

Three different stimulus conditions during response-reinforcer delays were conducted. For three groups (6 each from the Forward Pairing, Backward Pairing, and No Pairing groups), the hopper light was illuminated during the first 5 s immediately after an effective lever press (Beg signal). Another group of 6 Forward Pairing subjects experienced that same condition except that the hopper light was illuminated after a 6-s delay following an effective lever press (6-s del signal). A control group that received no stimuli during the delay (No signal) was comprised of the other 6 No Pairing subjects. The comparison of the greatest interest was between the groups that differed in whether they experienced light-food pairings during magazine training but received the immediate hopper light signal during acquisition. If conditioned reinforcement plays a role in beginning-signal effects, then the group that experiences the pairings should acquire lever pressing faster. Another comparison of interest was between the Beg signal and Delayed signal groups.

CHAPTER IV

RESULTS

Experiment 1 – Immediate Versus Delayed Response-Contingent Food-Paired Stimuli

CR Acquisition

All four forward pairing groups acquired hopper-checking during hopper light presentations with approximately the same speed. Only one subject did not exhibit hopper checking but was moved to the lever acquisition phase after 12 sessions anyway because it was in the No Signal group. The group means for number of sessions needed to reach the 80% CR criterion were 5.86, 4.43, 5.86, and 5.57 for the No Signal, 0-s, 3-s and 12.5-s groups, respectively. Group differences were not statistically significant [$F(3, 24) = .60, p = ns$] and pairwise comparison of the groups using Tukey's HSD test showed that no two groups were significantly different from each other.

A comparison between forward and backward pairing subjects in the percent of trials in which a CR occurred is presented in Figure 1. Only the first 3 sessions are shown because these are the only sessions in which all of the subjects (except for 1 forward pairing subject, which was excluded from the analysis) were still participating in this phase of the experiment. The forward pairing group showed an increase in CRs across sessions while the backward pairing group did not. A mixed ANOVA was performed on these data with session as a within-subjects factor and pairing type as a between-subjects factor. The main effect of session was statistically significant [$F(2, 64) = 16.92, p < .001$] but the main effect of pairing type was not [$F(1, 32) = 1.40, p = ns$]. The interaction was statistically significant [$F(2, 64) = 11.43, p < .001$]. Individual within-

subjects ANOVAs performed on the forward and backward pairing groups revealed a significant effect of session for the forward pairing group [$F(2, 52) = 95.97, p < .001$] but not for the backward pairing group [$F(2, 12) = 0.38, p = ns$].

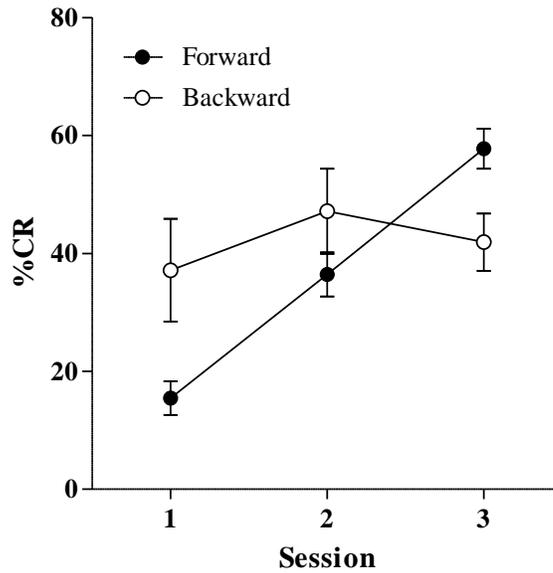


Figure 1. Mean %CR across sessions (+/- 1 S.E.M.) from Experiment 1.

Lever acquisition

One subject from the 3'' group was excluded from analysis due to failing health that surfaced mid-experiment. Lever response rates averaged by group across the 20 acquisition sessions are displayed in the top panel of Figure 2. The 0-s/For group consistently responded at higher rates than all of the other groups. The 3-s group exhibited the next highest response rates, followed by the 0-s/Back group, although the differences between the 0-s/Back group and the other two groups were completely absent over the final 7 sessions. The ANOVA (with Huynh-Feldt degrees-of-freedom correction for unequal variances in the within-subjects factor) performed on the response rate data showed significant main effects of session [$F(3.42, 99.27) =$

27.27, $p < .001$] and group [$F(4, 29) = 5.82, p < .01$]. The interaction of session and group was not statistically significant [$F(13.69, 99.27) = 1.25, p = ns$]. Tukey's HSD test showed the 0-s/For group to be significantly different from all other groups except for the 3-s group [all significant $ps < .01$]. The 3-s group was also significantly different from the other 3 groups [all significant $ps < .05$]. None of the other groups were significantly different from one another.

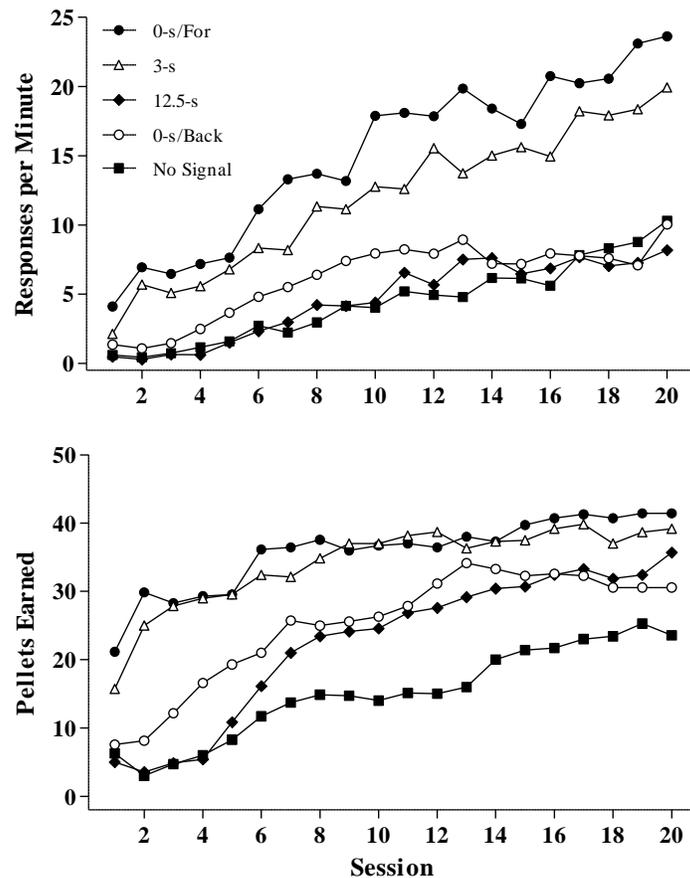


Figure 2. Mean response rate and pellets across sessions (+/- 1 S.E.M.) from Experiment 1.

Pellets Earned

Pellets earned averaged by group across the 20 acquisition sessions are displayed in the bottom panel of Figure 2. The 0-s/For group and 3-s groups consistently earned more pellets than

the other groups. The 0-s/Back and 12.5-s groups exhibited the next most pellets earned, followed by the No Signal group, which earned the least of any group. The omnibus ANOVA (again with Huynh-Feldt degrees-of-freedom correction for unequal variances in the within-subjects factor) performed on the pellets earned data showed significant main effects of session [$F(4.89, 141.90) = 38.53, p < .001$] and group [$F(4, 29) = 6.12, p < .01$]. The interaction of session and group was not statistically significant [$F(19.57, 141.90) = 1.41, p = ns$]. Tukey's HSD test showed the 0-s/For group to be significantly different from all other groups except for the 3-s group [all significant $ps < .05$]. The 3-s group was significantly different from the 12.5" and No Signal groups [$ps < .05$] but not the 0-s/Back group. The 0-s/Back group was also significantly different from the No Signal group [$p < .05$].

Experiment 2 – Delay Versus Trace Conditioning During Stimulus-Food Pairing

CR Acquisition

Only 4 of 12 subjects in the 5" trace group achieved the 80% CR criterion within 10 sessions. The %CR exhibited in the final magazine training session before lever press acquisition for each subject is presented in Figure 3. Note that while the individual subjects within groups experienced different numbers of CR acquisition sessions, each group experienced the same average number of sessions because one subject from each of the 0- and 2-s groups was yoked to one subject from the 5-s group. The ANOVA performed on the %CR data from the final session of magazine training showed that the groups differed significantly from one another [$F(2, 35) = 6.04, p < .01$]. A post hoc Tukey test indicated that the 0" trace group showed significantly more

hopper checking during hopper light illumination than the other two groups [$ps < .05$], which did not differ significantly from each other.

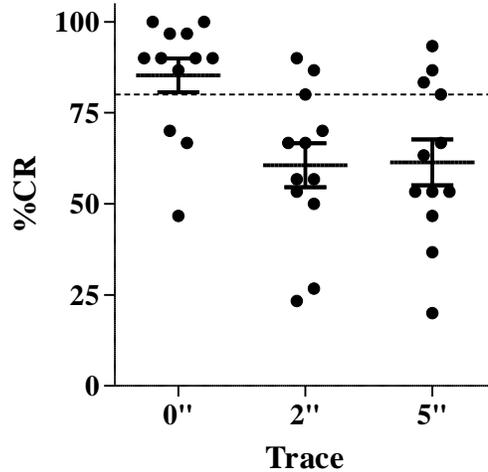


Figure 3. %CR from the final magazine training session (± 1 S.E.M.) from Experiment 2. Dashed horizontal line demarcates 80% CR criterion.

Lever Acquisition

Several problems [4 hopper malfunctions (SD208 session 11, SD223 session 8, SD226 session 19, and SD 231 session 2), 1 illness (SD227 sessions 15-20), and 1 incorrect protocol due to experimenter error (SD216 session 3)] arose that affected the lever acquisition data for a total of 6 out of the 36 total subjects. By coincidence, all 6 were from the Beg Sig group. The affected *sessions* have been excluded from the data presented on Figure 4 and the *subjects* have been excluded from the ANOVA conducted on both the lever press and pellets earned data.

Considering all 20 acquisition sessions, the signal at the beginning of the delay had little effect in the 0'' Trace subjects and a moderate facilitative effect in the 2'' and 5'' Trace groups. Statistical analysis using three-way ANOVA shows only the main effect of session to be significant

[$F(1.90, 45.60) = 6.81, p < .01$]. The main effects of trace and signal and all of the interactions were nonsignificant [all $ps > .22$].

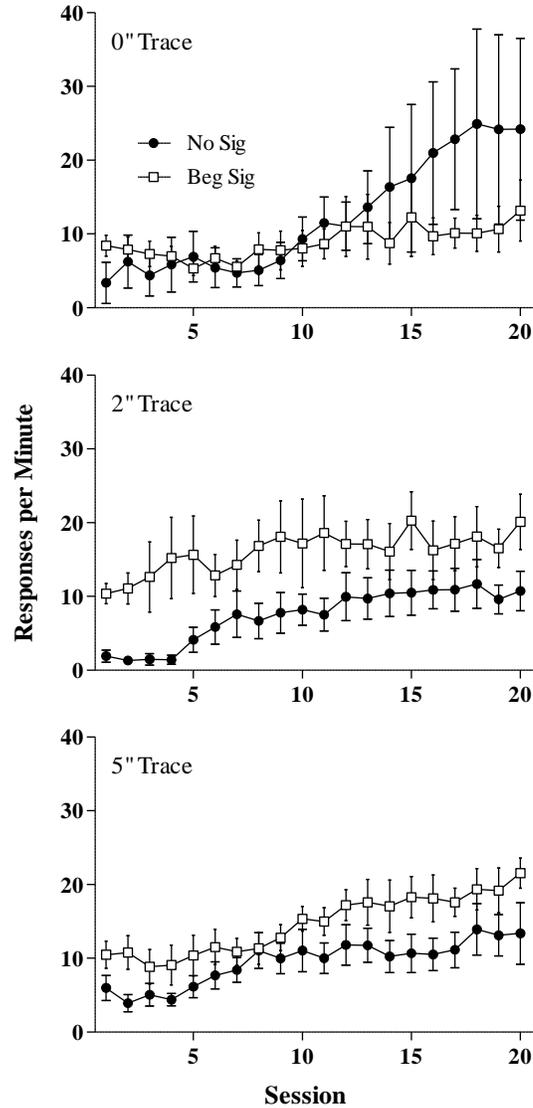


Figure 4. Mean response rates across sessions (+/- 1 S.E.M.) from Experiment 2.

To explore if any effect of the signal could be detected, the first session of lever press acquisition alone was subjected to further analysis. This was warranted by the clear signal effect present in Experiment 1 and the possibility that any effect may have been obscured by the

relatively large within-group variability that emerged in later sessions. For the purposes of statistical analysis, the first session was divided into 10 3-min bins and the number of responses emitted by each individual subject in these bins was tabulated. These data are presented in Figure 5. The subjects that were excluded from the previous analysis due to corrupted data are included in the present analysis as all of the issues that may have impacted the data occurred after the first lever press acquisition session. The ANOVA performed on these data indicates main effects of bin number [$F(6.11, 183.29) = 2.77, p < .05$] and signal [$F(1, 30) = 20.91, p < .001$], as well as a significant bin x signal interaction [$F(6.11, 183.29) = 2.70, p < .05$]. The main effect of trace and the other interactions were all nonsignificant [all $ps > .63$]. Post hoc analysis of the bin x signal interaction showed a significant effect of bin for the Beg Sig subjects [$F(5.90, 100.28) = 4.27, p < .01$] but not the No Sig subjects [$F(3.73, 63.48) = 0.59, p = ns$].

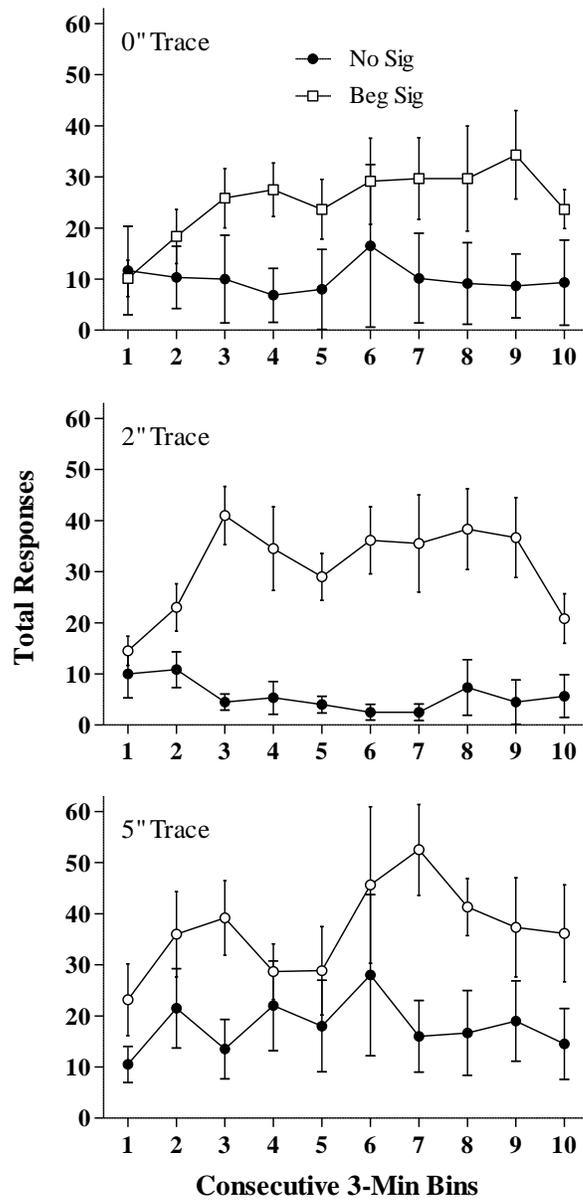


Figure 5. Mean binned responses (+/- 1 S.E.M.) from the first lever acquisition session of Experiment 2.

Pellets Earned

The number of pellets earned for each trace group and signal condition are shown in Figure 6. The Beg Sig subjects began earning large amounts of pellets in the first session of lever

press acquisition and continued throughout the remaining 19 sessions. An effect of the signal is apparent for all three trace groups, as the No Sig subjects required several sessions to increase to the level exhibited by the Beg Sig subjects starting from the first session. The trace groups are not obviously different from one another. The ANOVA performed on these data shows significant main effects of session [$F(8.09, 194.22) = 15.46, p < .001$] and signal [$F(1, 24) = 15.04, p < .01$] and a significant interaction between the two [$F(8.09, 194.22) = 11.65, p < .001$]. The main effect of trace was nonsignificant [$F(2, 24) = 1.45, p = ns$] along with all of the interactions involving this variable. Post hoc analysis of the session x signal interaction indicates that the Beg Sig subjects did not change significantly across sessions [$F(11.45, 103.08) = 0.79, p = ns$] while the No Sig subjects did [$F(7.44, 111.59) = 26.89, p < .001$].

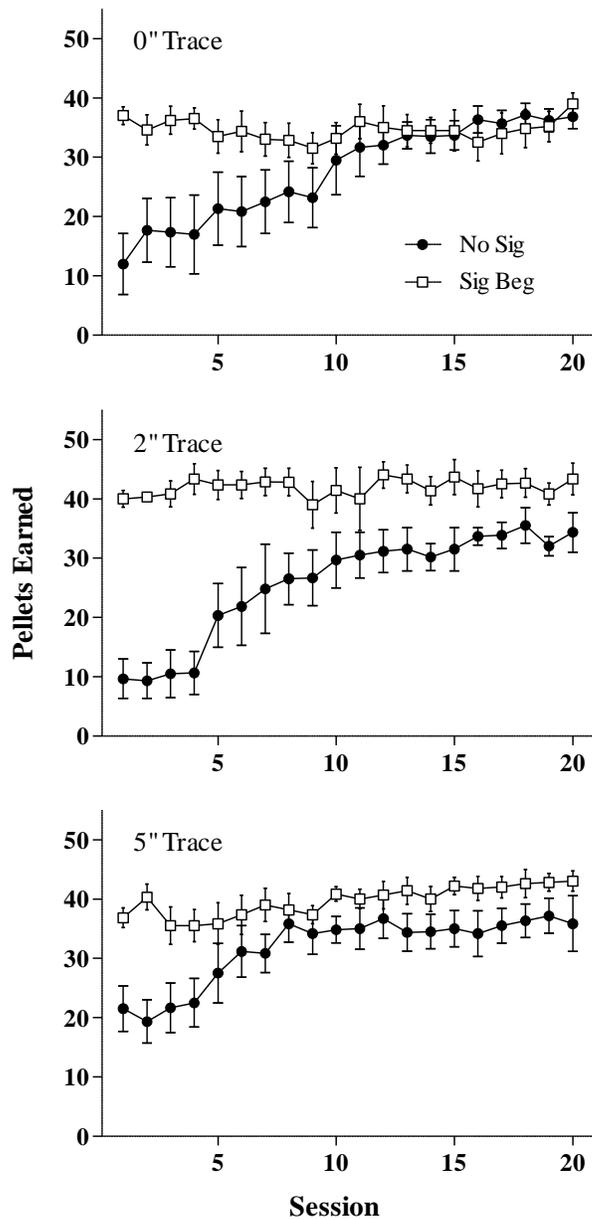


Figure 6. Mean pellets earned across sessions (+/- 1 S.E.M.) from Experiment 2.

Experiment 3 – Diffuse Versus Localized Food-Paired Stimuli

CR Acquisition

The mean number of sessions to reach the 80% CR criterion for the groups was 4.38 for the hopper light group and 4.13 for the houselight group. Most subjects in both groups took 3 or 4 sessions to reach 80%. (One subject did not achieve 80% CR within 10 sessions was given a score of 11 for the purposes of group comparison.) A *t*-test showed the mean difference to be nonsignificant [$t(14) = 0.23, p = ns$].

A comparison between the hopper light and houselight groups in the percent of trials in which a CR occurred is presented in Figure 7. Only the first 3 sessions are shown because these are the only sessions in which all of the subjects were still participating in this phase of the experiment. Both groups show similar starting points and slopes of acquisition. A mixed ANOVA was performed on these data with session as a within-subjects factor and signal type as a between-subjects factor. The main effect of session was statistically significant [$F(2, 28) = 50.84, p < .001$] but the main effect of signal type was not [$F(1, 14) = 0.03, p = ns$]. The interaction was also nonsignificant [$F(2, 28) = 1.07, p = ns$].

An additional analysis was conducted to determine if there were group differences in latencies between light onset and hopper-checking. Latencies from each subject's final magazine training session were averaged, yielding a single mean latency for each subject. These means are plotted in Figure 8. While the houselight group showed slightly lower latencies, on average, the group difference was not significant [$t(14) = 1.46, p = ns$].

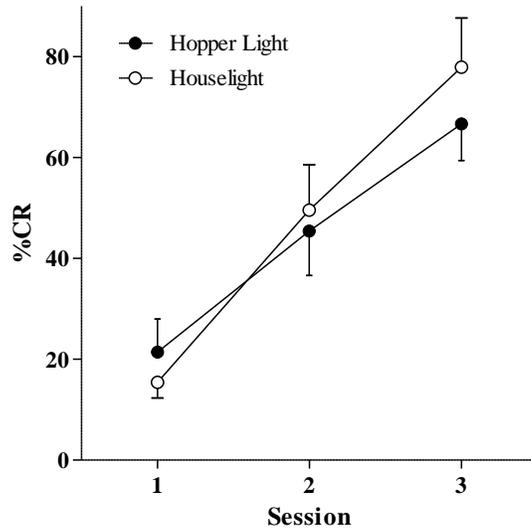


Figure 7. Mean %CR across the first 3 sessions for each group (+/- 1 S.E.M.) from Experiment 3.

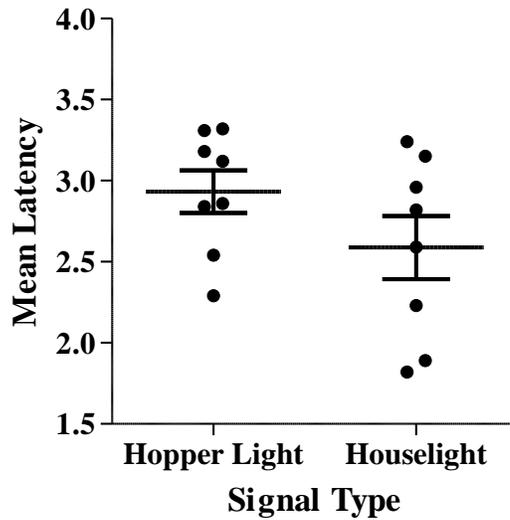


Figure 8. Mean latency to respond to light onset from the final magazine training session for each subject and group means (+/- 1 S.E.M.) from Experiment 3.

Lever Acquisition

Lever presses per minute for both the hopper light and houselight groups are shown in the top panel of Figure 9. Both groups increased steadily across the 20 acquisition sessions with the

hopper light group emitted slightly higher response rates on average. This group contained the subject that emitted by far the highest response rates (over 100 per min by session 20) out of all subjects and this likely accounts for mean differences observed. The ANOVA performed on these data shows a significant main effect of session [$F(1.79, 25.10) = 10.29, p < .01$] but a nonsignificant effect of stimulus type [$F(1, 14) = 0.50, p = ns$]. The interaction was also nonsignificant [$F(1.79, 25.10) = 0.21, p = ns$].

Pellets Earned

Pellets earned per session for both the hopper light and houselight groups is presented in the bottom panel Figure 9. Both groups began earning large numbers of pellets in the first session and increased slightly across the remaining 19 sessions. The modest but nonsignificant group differences observed in response rate are not evident in the pellets earned data. The ANOVA performed on these data indicate a significant main effect of session [$F(7.28, 101.97) = 6.37, p < .001$] but neither a significant main effect of signal type [$F(1, 14) = 0.97, p = ns$] nor a significant interaction [$F(7.28, 101.97) = 0.66, p = ns$].

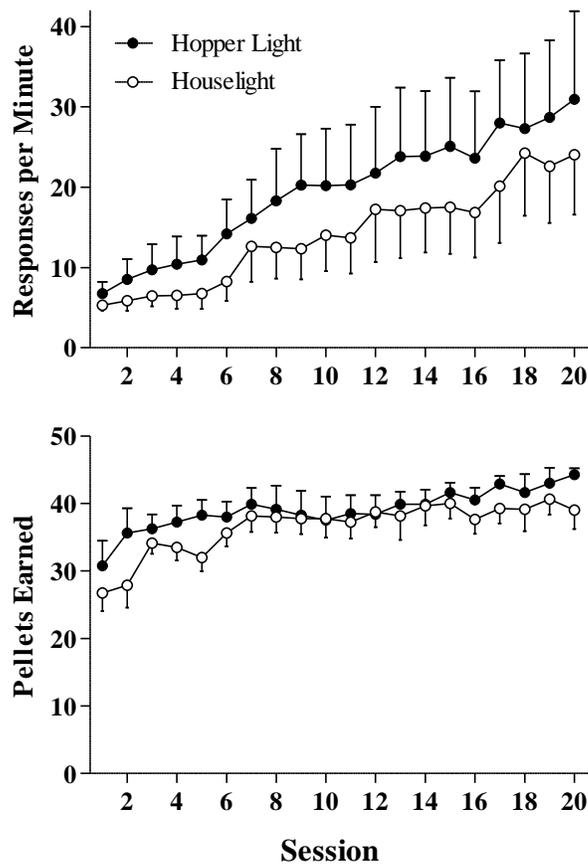


Figure 9. Mean response rate and pellets earned across sessions (+/- 1 S.E.M.) from Experiment 3.

Experiment 4 – Marking Versus Conditioned Reinforcement

CR Acquisition

All 12 subjects that received forward pairing achieved the 80% CR criterion within 9 sessions. Note again that the individual subjects within each group experienced different numbers of CR acquisition sessions but that the No + Beg, No + No, and Back + Beg groups all experienced the same average number of sessions as the For + Beg group because one subject from each of those groups was yoked to one subject from the For + Beg group. The %CR

exhibited in the final magazine training session before lever press acquisition for each subject is presented in Figure 10. The ANOVA performed on the %CR data from the final session of magazine training showed that the groups differed significantly from one another [$F(4, 29) = 13.42, p < .001$]. A post hoc Tukey test indicated that both Forward pairing groups showed significantly more hopper checking during hopper light illumination than the other three groups [$ps < .05$], but were not different from each other. Additionally, the No Signal groups did not differ significantly from one another, nor from the Backward pairing group.

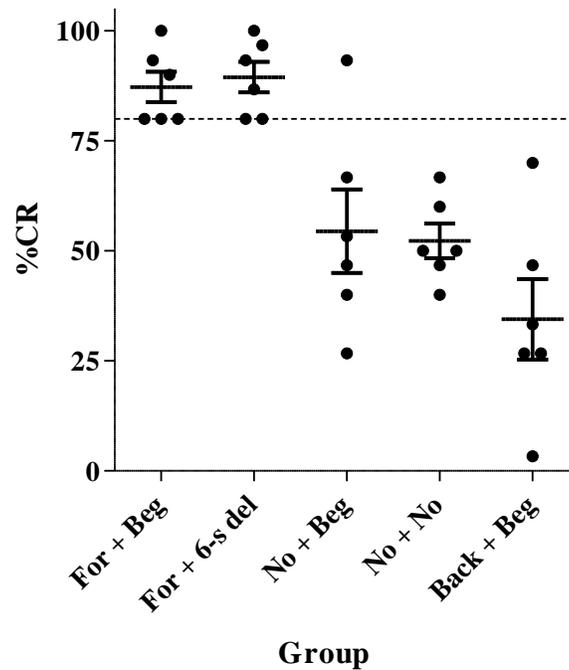


Figure 10. %CR from the final magazine training session for each subject and group means (± 1 S.E.M.) from Experiment 4. Dashed horizontal line demarcates 80% CR criterion.

Lever Acquisition

The data from Experiment 4 are presented and analyzed differently from the other experiments for two reasons. First, because only a single session was conducted it was easier to

display the data for individual subjects in a single figure. Second, because lever pressing was so erratic from moment to moment both within- and between-groups, the data are presented in cumulative fashion to enhance clarity. For the purposes of analysis, the 4-h acquisition sessions were broken up into 24 10-min bins and lever presses occurring during each 10-min period were tabulated. The resultant data are presented in cumulative fashion in Figure 11. Almost every subject acquired lever pressing within the single 4-h period. Within-group variability was generally high. For instance, the No + No group, which neither received light-food pairings prior to lever press acquisition nor a delay signal during acquisition, contained both the subjects with highest and second-to-lowest lever press totals. Obvious quantitative differences among the groups are not apparent. The ANOVA performed on the raw lever press totals (not cumulative responses) showed a significant main effect of bin [$F(6.83, 170.74) = 2.99, p < .01$] but neither a main effect of group [$F(4, 25) = 0.63, p = ns$] nor an interaction of bin and group [$F(27.32, 170.74) = 0.83, p = ns$]. Because pairwise comparisons between a few of the individual groups were of particular interest, a Tukey test was conducted despite the lack of group differences. No group was significantly different from any other group [all $ps > .66$].

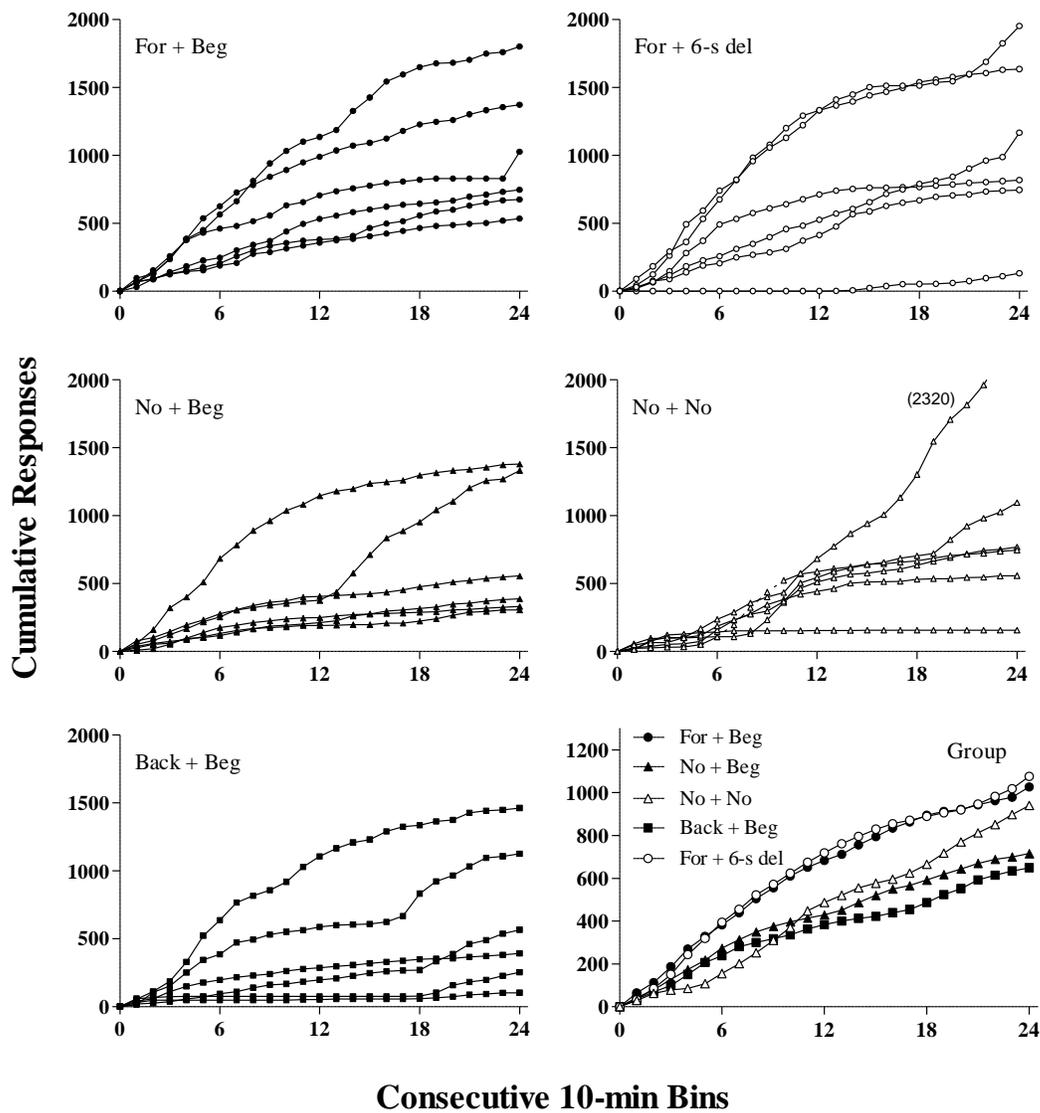


Figure 11. Cumulative responses for each subject and group (lower right panel) across 10-min bins from Experiment 4.

While differences between the groups across the entire 4-hr session are not evident, it could be the case that differences were present during the early part of the session and were obscured by considering the 4-hr session as a whole. Therefore, a second analysis of lever pressing was conducted which considered only the first 30 min of the session broken up into 10

3-min bins. These data are presented in cumulative fashion in Figure 12. All but one subject were responding to some extent within the first 30 min of the session. Out of the 5 groups, the No + No and Back + Beg groups appear to show the least lever responding, while the For + Beg group seems to show the most consistently high responding across all 6 subjects. The ANOVA performed on the raw lever press totals (not cumulative responses) showed nonsignificant main effects of bin [$F(7.98, 199.51) = 1.10, p = ns$] and group [$F(4, 25) = 0.69, p = ns$] and a nonsignificant interaction of bin and group [$F(31.92, 199.51) = 0.81, p = ns$]. Again, a Tukey test was conducted despite the lack of group differences. No group was significantly different from any other group [all $ps > .68$].

Pellets Earned

Only the pellets earned during the first 30 min of the session were analyzed. The group data, again split into 3-min bins, are presented in cumulative fashion in Figure 13. The For + Beg group earned the most pellets over the first 30 min and the No + No group earned the least. The ANOVA performed on the raw pellets earned totals (not cumulative pellets earned) showed a significant main effect of group [$F(4, 25) = 3.42, p < .05$] but neither a main effect of bin [$F(8.82, 220.38) = 1.33, p = ns$] nor an interaction of bin and group [$F(35.26, 220.38) = 1.28, p = ns$]. A Tukey test revealed that the For + Beg group was significantly different from the No + No group [$p < .05$], but that no other pair of groups were significantly different.

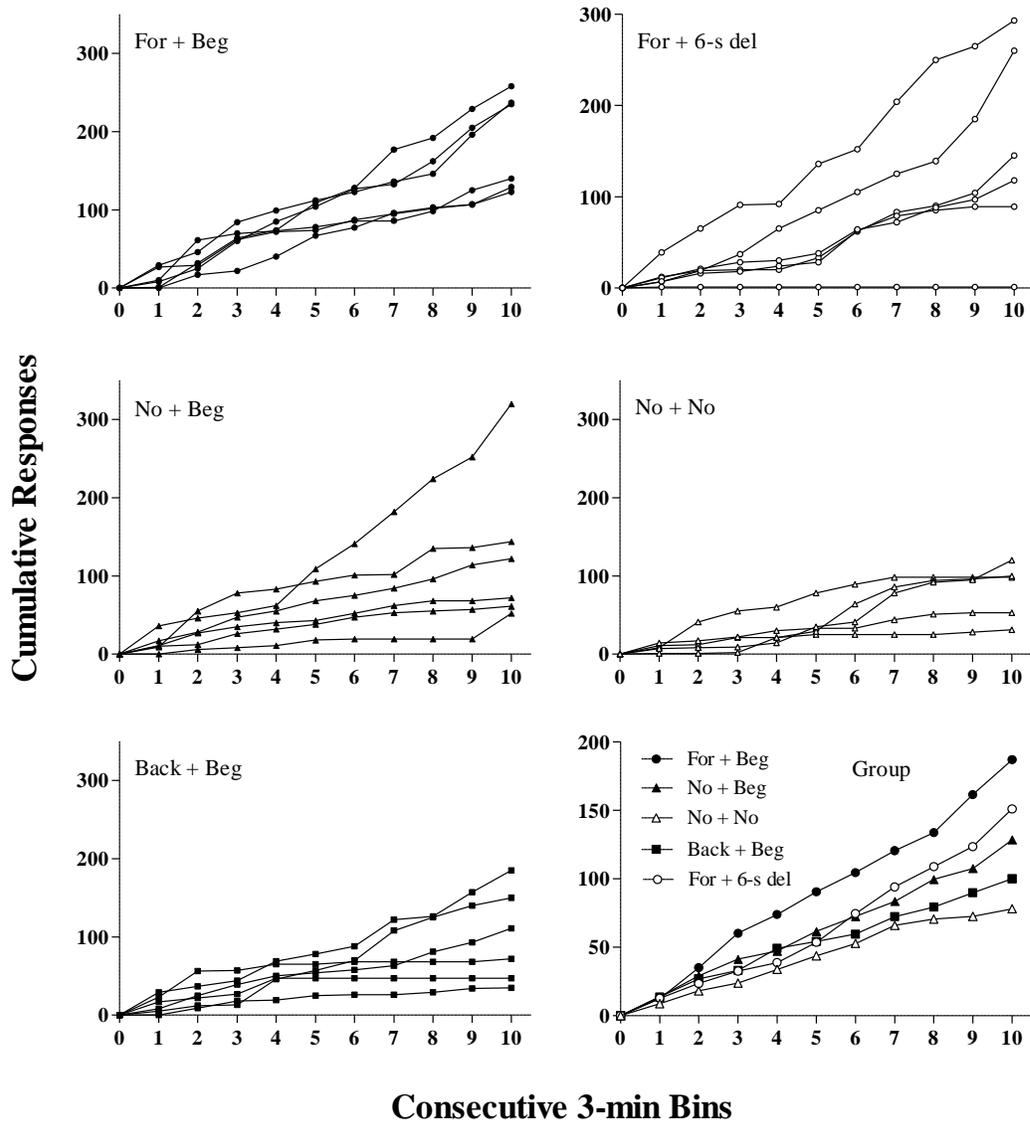


Figure 12. Cumulative responses for each subject and group (lower right panel) across the first 30 min from Experiment 4.

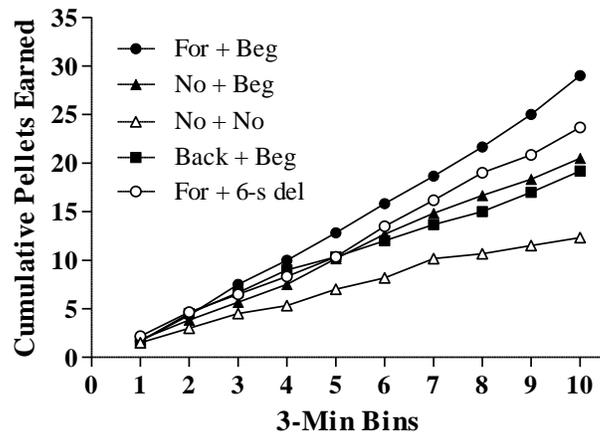


Figure 13. Cumulative pellets earned for each group across the first 30 min from Experiment 4.

CHAPTER V

DISCUSSION

The effects of response-contingent food-paired stimuli on response acquisition with delayed reinforcement were examined across four experiments. In Experiment 1, it was shown that inserting a delay between a response and the response-contingent food-paired stimulus is sufficient to reduce its effectiveness in enhancing response acquisition, as long as the delay is long enough. Additionally, whether the food-paired stimulus preceded or followed food during pre-acquisition training modulated the function of the food-paired stimulus; subjects receiving forward pairing acquired lever pressing more quickly than controls while subjects receiving backward pairing were no better than controls. In Experiment 2, the manner of stimulus-food pre-training (whether trace or delay conditioning) was shown to affect hopper-checking during pre-training but not lever press acquisition itself; the presentation of the food-paired stimulus at the beginning of the response-reinforcer delay during lever press acquisition enhanced acquisition equally regardless of the conditions during pre-training. In Experiment 3, it was shown that a diffuse signal (house light) was just as effective as the localized signal (hopper light) that was used in the other experiments, both in terms of elicitation of hopper-checking and effect on lever press acquisition. In Experiment 4, it was shown that the amount of hopper-checking elicited by the light paired with food is beyond that which is engendered by mere presentation of food pellets without the preceding light presentation. Also, using a single 4-hr lever press acquisition session, no differences in response rate were observed between groups experiencing a response-contingent delay stimulus; whether that stimulus was delayed by 6-s, previously explicitly not paired with food, or not previously presented at all did not matter. The only

difference observed was in pellets earned between the no-signal control and the group that received both forward pairing and the immediate beginning signal.

Efforts to show a measurable behavioral effect of the signal prior to operant response acquisition were successful. In Experiment 1, the subjects that experienced forward light-food pairing showed an increase in hopper entries during light onset while subjects that experienced backward pairing did not. This result was replicated in Experiment 4 with the addition of subjects that experienced no signal and also did not show an increase in head-in-hopper behavior. In Experiment 2, most of the subjects that experienced either a 2- or 5-s trace interval between the light and food did not achieve the head-in-hopper acquisition criterion within 10 sessions. Most of the subjects that experienced contiguous light-food pairing exhibited strong head-in-hopper behavior within a few sessions. In Experiment 3, head-in-hopper acquisition proceeded equally between subjects experiencing either a localized or diffuse signal; both groups acquired hopper-checking during light onset with approximately equal rapidity. Surprisingly, the acquired signal function during this phase has little bearing on the operant response acquisition with delayed reinforcement phase. The only obvious effect of the pre-pairing phase was in Experiment 1, where the subjects in the backward pairing group showed slower lever press acquisition than subjects in the forward pairing group. This effect did not replicate in Experiment 4.

Previous studies of RADR using delay signals that include a prepairing phase prior to operant response acquisition have not typically ensured that the food-paired signal affects behavior (Fox & Reilly, 2010; Williams et al., 1990). It is unclear in these studies, therefore, just to what extent the prepairing affects RADR with signals. With evidence that the signal affects

behavior prior to operant response acquisition, one can be sure that a small or null effect of the signal on operant response acquisition is not due to ineffective prepairing but is due to the arrangement during operant response acquisition. That future experiments ensure the effectiveness of signals during prepairing is especially important in light of failures to replicate signal effects that cannot be clearly attributed to either the prepairing or operant acquisition phases of an experiment (cf. Fox & Reilly, 2010).

Briefly signaling the response-reinforcer delay enhances response acquisition with delayed reinforcement (Critchfield & Lattal, 1993; Pulido et al., 2005; Schlinger & Blakely, 1994; Williams, 1999) relative to conditions in which no signal is present. Experiments 1, 2, and 4 all at least partially replicate this effect. In Experiment 1, the group that had the immediate brief signal during lever acquisition responded at higher rates and earned more pellets than the no signal control group. An enhancing effect of equal magnitude was also shown for the group that received the brief signal after a 3-s delay, which appears to be a novel finding. When the signal was delayed by 12.5 s, however, it had no effect on response rate and a moderate but nonsignificant enhancing effect on pellets earned. This group is notable because a previous steady-state experiment included a condition where the middle of the response-reinforcer delay was interrupted by a signal (Williams et al., 1990, Experiment 2). In this experiment, the signal *decreased* responding maintained by the delayed reinforcer, which was not replicated in the present experiment. One group experienced an immediate response-produced signal but showed a markedly weakened enhancing effect: the backward pairing group. This group's prior experience with the light explicitly predicting the absence of food caused their mean response

rate to be similar to the 12.5-delay and no signal groups. This group did, however, earn more pellets than the no signal group.

Experiment 2 also showed a beginning-signal effect. While response rates over the entire 20 sessions were not significantly different between signal and no signal groups, response rates across the first acquisition session, where the effect would be expected to be largest, were markedly different. Additionally, more pellets were earned by subjects that experienced the response-produced signal than those that did not. This was true regardless of the subjects' prior experience with respect to the light stimulus.

Experiment 4 provides mixed evidence for a brief signal effect. It should be noted first and foremost that, based solely upon response rates, only a small and nonsignificant signal effect was apparent for both groups that received forward pairing and either an immediate or delayed brief signal. Looking solely at pellets earned during the early part of response acquisition, there was a detectable difference between the forward pairing subjects that received an immediate signal and the no signal control, thus replicating the effect again. Why the beginning-signal effect in subjects that have experienced prepairing is much smaller in this experiment relative to Experiment 1 is unknown.

Three hypotheses about the mechanism underlying beginning-signal effects have been put forth. The first, conditioned reinforcement, traditionally posits that delay signals acquire response rate-enhancing function via Pavlovian conditioning, i.e., pairing with an already-established reinforcer. Stimuli that would otherwise serve no function (such as a light) gain the capacity to reinforce behavior due to repeated pairing. The second, the "marking" hypothesis, states that signals occurring immediately after a behavior but well before a reinforcer serve to

“mark” the behavior in memory, making the behavior more likely to be recalled when the reinforcer is finally delivered. In this manner, delayed reinforcers that are briefly signaled can be just as effective as signals contiguous with reinforcers in strengthening behavior. The third, sensory reinforcement, states that novel stimulus changes serve to reinforce behavior directly, at least for a short time. No pairing or memory process is necessary for the observation of such an effect.

None of these three hypotheses can neatly account for all of the empirical findings regarding briefly signaled response-reinforcer delays. A traditional Pavlovian-oriented conditioned reinforcement account has no trouble with Experiment 1 reported here, where a signal that has already been paired with food exerts an enhancing effect on response acquisition when presented as a brief signal, but it cannot explain experiments where signal effects are observed despite the signal never having been presented within 25 s of the primary reinforcer (e.g., Williams, 1999). To consistently apply the logic of a conditioned reinforcement account, one must assume that trace conditioning between the signal and the primary reinforcer is occurring despite a 25-s trace interval. By most accounts, this is not a reasonable assumption. The marking hypothesis, however, does not have difficulty explaining such effects. Instead, the marking hypothesis does not take into account prior experience with the signals and thus does little to explain effects as in Experiment 1 reported here, where forward and backward pairing of the signal and food exert different effects on behavior when the signal is used as a brief stimulus (i.e., a stimulus that signals the beginning of a response-reinforcer delay) during lever press acquisition with delayed reinforcement. In both cases, the stimuli are presented following the response that needs to be remembered during response acquisition and, thus, should be equally

able to “mark” the response in memory. The sensory reinforcement hypothesis suffers a similar pitfall. Two brief stimuli that are equivalent in form and novelty should presumably be equal in their reinforcing capacity. Additionally, brief signal effects have been observed in several steady-state procedures (e.g., Schaal & Branch, 1988) in which the novelty of the stimulus change would presumably erode with experience. Yet, brief signals in these procedures maintain their reinforcing function indefinitely.

Because each of these three potential explanations of brief signal effects is inadequate, trying to decide which is best would seem fruitless. A modified conditioned reinforcement approach might offer a more compelling explanation. This approach assumes that a conditioned reinforcer is one that acquires its function via experience and that the experience need not necessarily be contiguous pairing with an already-established reinforcer, but that pairing does have a facilitative effect. All beginning-signal effects are thus subsumed under this mechanism, including ones in which the signal is never directly paired with the reinforcer. Shedding the restriction that conditioned reinforcement comes about purely through Pavlovian conditioning allows for the consideration of other arrangements that can imbue a signal with response-increasing function. One such arrangement is that a neutral stimulus signals the beginning of a delay to reinforcement. There is no *a priori* reason to presume that this arrangement should not affect the function of such a stimulus; indeed, it does. The response-contingent presentation of such a stimulus increases the probability of the response; therefore, the stimulus is a reinforcer. If the stimulus is too brief relative to the length of the delay or if the delay is too long, the effect is weakened, much as too small a magnitude of reinforcement or too lean a schedule of reinforcement will not maintain behavior.

Having said that, the only arrangement in the present set of experiments where a beginning-signal effect could have been observed in the absence of a prior history of pairing with the primary reinforcer was the No + Beg group from Experiment 4, which did not acquire lever-pressing significantly faster than no-signal controls. This was also the case in Fox & Reilly (2010, Experiment 1), which also observed response acquisition under a 30-s delay of reinforcement with and without a 5-s beginning signal. It appears that, in the absence of a history of signal-reinforcer pairing, the beginning-signal effect is not likely to occur using such large response-reinforcer delays. It should be noted, however, that both Williams (1999) and Rull et al. (2008) observed such effects using 30- and 32-s response-reinforcer delays, respectively.

It should be noted that in Rull et al., the beginning-signal effect was stronger with signals that extended further into the response-reinforcer delay, which closely parallels the findings of Schaal and Branch (1990), who examined pigeons' response rates on VI schedules with a 27-s response-reinforcer delay across various signal durations. Schaal and Branch found a direct relationship between signal duration and response rate; as the signal duration was increased, so did response rates. In this case, both steady-state and acquisition procedures show the same thing; signals that span larger portions of response-reinforcer delays have bigger effects on responding. Further, in our Experiment 4, a beginning-signal effect was observed for those subjects that had already experienced signal-reinforcer pairing, which closely parallels another finding from Schaal and Branch (1990), namely, that once subjects had already experienced a completely signaled delay, response rates under partially-signal delays were higher than they were initially. This indicates that a prior history of signal-reinforcer pairing is effective in increasing the effectiveness of beginning-of-delay signals in both steady-state and acquisition

procedures. Overall, the variables that affect the function of beginning-of-delay signals appear to be similar across procedures and parsimoniously suggest that the underlying mechanism is likely the same in both types of procedures.

Response acquisition with delayed reinforcement was studied in four experiments. Response acquisition was generally robust, replicating the well-established phenomenon of RADR. Relatively brief food-paired stimuli presented at or near the beginning of response-reinforcer delays enhanced acquisition. That a delayed brief signal can enhance response acquisition to the same extent as an immediate one is a novel finding. The previous experience of the stimulus predicting the absence of food partially negated the beginning-signal effect but did not disrupt acquisition to below the levels exhibited by subjects in unsigned conditions. Trace pairing did not disrupt the beginning-signal effect nor did the use of a diffuse rather than localized stimulus. Further experiments might explore the delayed beginning-signal effect further by including more delay values and determining the importance of prepairing to the effect. Additionally, more research is needed that addresses the effect of the proportion of the delay that is filled with stimulus onset in acquisition rather than steady-state procedures to further validate that the underlying mechanism is the same across procedures.

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